Space Time Spreading and Phase Sweep Transmit Diversity

Related Application

Related subject matter is disclosed in the following applications filed concurrently and assigned to the same assignee hereof: U.S. Patent Application Serial No. ______________ entitled, "Symmetric Sweep Phase Sweep Transmit Diversity," inventors Roger Benning, R. Michael Buehrer, Paul A. Polakos and Mark Kraml; U.S. Patent Application Serial No. ______________ entitled, "Biased Phase Sweep Transmit Diversity," inventors Roger Benning, R. Michael Buehrer and Robert Atmaram Soni; and U.S. Patent Application Serial No. ______________ entitled, "Split Shift Phase Sweep Transmit Diversity," inventors Roger Benning, R. Michael Buehrer, Robert Atmaram Soni and Paul A. Polakos.

Background of the Related Art

Performance of wireless communication systems is directly related to signal strength statistics of received signals. Third generation wireless communication systems utilize transmit diversity techniques for downlink transmissions (i.e., communication link from a base station to a mobile-station) in order to improve received signal strength statistics and, thus, performance. Two such transmit diversity techniques are space time spreading (STS) and phase sweep transmit diversity (PSTD).

FIG. 1 depicts a wireless communication system 10 employing STS. Wireless communication system 10 comprises at least one base station 12 having two antenna elements 14-1 and 14-2, wherein antenna elements 14-1 and 14-2 are spaced far apart for achieving transmit diversity. Base station 12 receives a signal S for transmitting to mobile-station 16. Signal S is alternately divided into signals s_e and s_o, wherein signal s_e comprises even data bits and signal s_o comprises odd data bits. Signals s_e and s_o are processed to produce signals S^{14-1} and S^{14-2}. Specifically, s_e is multiplied with Walsh code w_1 to produce signal $s_e w_1$; a conjugate of signal s_o is multiplied with Walsh code w_2 to produce signal $s_o^* w_2$; signal s_o is multiplied with Walsh code w_1 to produce $s_o w_1$; and a conjugate of signal s_e is multiplied with Walsh code w_2 to produce $s_e^* w_2$. Signal $s_e w_1$ is added to signal $s_o^* w_2$ to produce signal S^{14-1} (i.e., $S^{14-1}=s_e w_1+s_o^* w_2$) and signal $s_e^* w_2$ is subtracted from signal $s_o w_1$ to produce signal S^{14-2} (i.e., $S^{14-2}=s_o w_1-s_e^* w_2$). Signals S^{14-1} and S^{14-2} are transmitted at substantially equal or identical power levels over antenna elements 14-1 and 14-2, respectively. For purposes of this application, power levels are "substantially equal" or "identical" when the power levels are within 1% of each other.

Mobile-station 16 receives signal R comprising $\gamma_1(S^{14-2})+\gamma_2(S^{14-2})$, wherein γ_1 and γ_2 are distortion factor coefficients associated with the transmission of signals S^{14-1} and S^{14-2} from antenna elements 14-1 and 14-2 to mobile-station 16, respectively. Distortion factor coefficients γ_1 and γ_2 can be estimated using pilot signals, as is well-known in the art. Mobile-station 16 decodes signal R with Walsh codes w_1 and w_2 to respectively produce outputs:

$$W_1=\gamma_1 s_e+\gamma_2 s_o \quad \text{equation 1}$$

$$W_2=\gamma_1 s_o^*-\gamma_2 s_e^* \quad \text{equation 1a}$$

Using the following equations, estimates of signals s_e and s_o, i.e., $\hat{s}_e$ and $\hat{s}_o$, may be obtained:

$$\hat{s}_e = \gamma_1^* W_1 - \gamma_2 W_2^* = s_e\left(|\gamma_1|^2 + |\gamma_2|^2\right) + noise \quad \text{equation 2}$$

$$\hat{s}_o = \gamma_2^* W_1 + \gamma_1 W_2^* = s_o\left(|\gamma_1|^2 + |\gamma_2|^2\right) + noise' \quad \text{equation 2a}$$

However, STS is a transmit diversity technique that is not backward compatible from the perspective of the mobile-station. That is, mobile-station 16 is required to have the necessary hardware and/or software to decode signal R. Mobile-stations without such hardware and/or software, such as pre-third generation mobile-stations, would be incapable of decoding signal R.

By contrast, phase sweep transmit diversity (PSTD) is backward compatible from the perspective of the mobile-station. FIG. 2 depicts a wireless communication system 20 employing PSTD. Wireless communication system 20 comprises at least one base station 22 having two antenna elements 24-1 and 24-2, wherein antenna elements 24-1 and 24-2 are spaced far apart for achieving transmit diversity. Base station 22 receives a signal S for transmitting to mobile-station 26. Signal S is evenly power split into signals s_1 and s_2 and processed to produce signals S^{24-1} and S^{24-2}, where $s_1=s_2$. Specifically, signal s_1 is multiplied by Walsh code w_k to produce $S^{24-1}=s_1 w_k$, where k represents a particular user or mobile-station. Signal s_2 is multiplied by Walsh code w_k and a phase sweep frequency signal $e^{j2\pi f_s t}$ to produce S^{24-2}, i.e., $S^{24-2}=s_2 w_k e^{j2\pi f_s t} = s_1 w_k e^{j2\pi f_s t} = S^{24-1} e^{j2\pi f_s t}$, where f_s is a phase sweep frequency and t is time. Signals S^{24-1} and S^{24-2} are transmitted at substantially equal power levels over antenna elements 24-1 and 24-2, respectively. Note that the phase sweep signal $e^{j2\pi f_s t}$ is being represented in complex baseband notation, i.e., $e^{j2\pi f_s t} = \cos(2\pi f_s t)+j\sin(2\pi f_s t)$. It should be understood that the phase sweep signal may also be applied at an intermediate frequency or a radio frequency.

Mobile-station 26 receives signal R comprising $\gamma_1 S^{24-1}+\gamma_2 S^{24-2}$. Simplifying the equation for R results in

$$R = \gamma_1 S^{24-1} + \gamma_2 S^{24-1} e^{j2\pi f_s t} \qquad \text{equation 3}$$

$$R = S^{24-1} \{\gamma_1 + \gamma_2 e^{j2\pi f_s t}\} \qquad \text{equation 3a}$$

$$R = S^{24-1} \gamma_{eq} \qquad \text{equation 3b}$$

where γ_{eq} is an equivalent channel seen by mobile-station 26. Distortion factor coefficient γ_{eq} can be estimated using pilot signals and used, along with equation 3b, to obtain estimates of signal s_1 and/or s_2.

In slow fading channel conditions, both transmit diversity techniques, i.e., STS and PSTD, improve performance (relative to when no transmit diversity technique is used) by making the received signal strength statistics associated with a slow fading channel at the receiver look like those associated with a fast fading channel. However, PSTD does not provide the same amount of overall performance improvement as STS. Additionally, in additive white gaussan noise (AWGN) conditions, PSTD can significantly degrade performance, whereas STS neither improves nor degrades performance. Accordingly, there exists a need for a transmission technique that provides the performance of STS and the backwards compatibility of PSTD without significantly degrading performance in AGWN conditions.

Summary of the Invention

The present invention is a method and apparatus for transmission that provides the performance of space time spreading (STS) or orthogonal transmit diversity (OTD) and the backwards compatibility of phase sweep transmit diversity (PSTD) without significantly degrading performance in additive white guassan noise (AWGN) conditions using a transmission architecture that incorporates STS/OTD and a form of PSTD referred to herein as biased PSTD, which involves transmitting a signal and a frequency swept version of the same signal over diversity antennas at different power levels to reduce the depths of nulls normally seen in AWGN conditions when PSTD is utilized.

In one embodiment, a signal s_1 comprising a non-STS/OTD signal and a first STS/OTD signal belonging to an STS/OTD pair is split into two signals $s_1(a)$ and $s_1(b)$, wherein the power level of signal $s_1(a)$ is higher than the power level of signal $s_1(b)$. The signal $s_1(b)$ is phase swept using a phase sweep frequency signal. Thus, signal s_1 is processed in accordance with biased PSTD. The phase swept signal $s_1(b)$ is added to a signal s_2 to produce a summed signal, wherein signal s_2 comprises a second STS/OTD signal belonging to the STS/OTD pair. The summed signal and the signal $s_1(a)$ are amplified and transmitted over a pair of diversity antennas. The amount of gain applied to the summed signal and the signal $s_1(a)$ may be equal or

unequal such that the amplified summed signal and the amplified signal $s_1(a)$ are at approximately equal power levels.

Brief Description of the Drawings

The features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where

FIG. 1 depicts a wireless communication system employing space time spreading techniques in accordance with the prior art;

FIG. 2 depicts a wireless communication system employing phase sweep transmit diversity in accordance with the prior art;

FIG. 3 depicts a base station employing code division multiple access (CDMA), a form of phase sweep transmit diversity (PSTD) referred to herein as biased PSTD, and space time spreading (STS) or orthogonal transmit diversity (OTD) in accordance with one embodiment of the present invention;

FIG. 4 depicts a base station employing CDMA, biased PSTD, and STS or OTD in accordance with another embodiment of the present invention; and

FIG. 5 depicts a base station employing CDMA, biased PSTD, STS or OTD, and split shift PSTD in accordance with another embodiment of the present invention.

Detailed Description

FIG. 3 depicts a base station 30 employing code division multiple access (CDMA), a form of phase sweep transmit diversity (PSTD) referred to herein as biased PSTD, and space time spreading (STS) or orthogonal transmit diversity (OTD) in accordance with the present invention. CDMA, PSTD, STS and OTD are well-known in the art.

Base station 30 provides wireless communication services to mobile-stations, not shown, in its associated geographical coverage area or cell, wherein the cell is divided into three sectors α, β, γ. Base station 30 includes a transmission architecture that incorporates STS or OTD and biased PSTD, as will be described herein.

Base station 30 comprises a processor 32, a splitter 34, multipliers 36, 38, 40, adder 42, amplifiers 44, 46, and a pair of diversity antennas 48, 50. Note that base station 30 also includes configurations of splitters, multipliers, adders, amplifiers and antennas for sectors β, γ that are identical to those for sector α. For simplicity sake, the configuration for sectors β, γ are not shown. Additionally, for discussion purposes, it is assumed that signals S_k are intended for

mobile-stations k located in sector α and, thus, the present invention will be described with reference to signals S_k being processed for transmission over sector α.

Processor 32 includes software for processing signals S_k in accordance with well-known CDMA and STS/OTD techniques, where STS/OTD indicates STS and/or OTD. The manner in which a particular signal S_k is processed by processor 32 depends on whether mobile-station k is STS/OTD compatible, i.e., mobile-station capable of decoding signals processed using STS/OTD. Processor 32 may also include software for determining whether mobile-station k is STS/OTD compatible. If mobile-station k is not STS/OTD compatible, then signal S_k is processed in accordance with CDMA techniques to produce signal $S_{k\text{-}1}$, which is also referred to herein as a non-STS/OTD signal $S_{k\text{-}1}$.

Note that, in another embodiment, processor 32 is operable to process signals S_k in accordance with a multiple access technique other than CDMA, such as time or frequency division multiple access. In this embodiment, when mobile-station k is not STS/OTD compatible, then signal S_k is processed in accordance with such other multiple access technique to produce the non-STS/OTD signal $S_{k\text{-}1}$.

If mobile-station k is STS/OTD compatible, then signal S_k is processed in accordance with CDMA and STS/OTD. Specifically, if mobile-station k is STS compatible, then signal S_k is processed using STS. Such process includes alternately dividing signal S_k into signals s_e and s_o, wherein signal s_e comprises even data bits and signal s_o comprises odd data bits. Signal s_e is multiplied with Walsh code w_1 to produce signal $s_e w_1$, and a conjugate of signal s_e is multiplied with Walsh code w_2 to produce $s_e{}^*w_2$. Signal s_o is multiplied with Walsh code w_1 to produce $s_o w_1$, and a conjugate of signal s_o is multiplied with Walsh code w_2 to produce signal $s_o{}^*w_2$. Signal $s_e w_1$ is added to signal $s_o{}^*w_2$ to produce signal $S_{k\text{-}2}(a) = s_e w_1 + s_o{}^*w_2$. Signal $s_e{}^*w_2$ is subtracted from signal $s_o w_1$ to produce signal $S_{k\text{-}2}(b) = s_o w_1 - s_e{}^*w_2)$. Signals $S_{k\text{-}2}(a)$, $S_{k\text{-}2}(b)$ are also referred to herein as STS signals, and together signals $S_{k\text{-}2}(a)$, $S_{k\text{-}2}(b)$ collectively comprise an STS pair.

If mobile-station k is OTD compatible, then signal S_k is processed using OTD. Orthogonal transmit diversity involves dividing signal S_k into signals s_e and s_o, and multiplying signals s_e and s_o using Walsh codes w_1, w_2 to produce signals $S_{k\text{-}3}(a)$, $S_{k\text{-}3}(b)$, i.e., $S_{k\text{-}3}(a)=s_e w_1$ and $S_{k\text{-}3}(b) = s_o w_2$, respectively. Signals $S_{k\text{-}3}(a)$, $S_{k\text{-}3}(b)$ are also referred to herein as OTD signals, and together signals $S_{k\text{-}3}(a)$, $S_{k\text{-}3}(b)$ collectively comprise an OTD pair.

For illustration purposes, the present invention will be described herein with reference to STS and signals $S_{k\text{-}2}(a)$, $S_{k\text{-}2}(b)$. It should be understood that the present invention is also applicable to OTD and signals $S_{k\text{-}3}(a)$, $S_{k\text{-}3}(b)$.

The output of processor 32 are signals $s_{\alpha-1}$, $s_{\alpha-2}$, where signal $s_{\alpha-1}$ comprises of signals S_{k-1} and S_{k-2}(a) and signal $s_{\alpha-2}$ comprises of signals S_{k-2}(b), i.e., $s_{\alpha-1}=\sum S_{k-1}+\sum S_{k-2}(\text{a})$ and $s_{\alpha-2}=\sum S_{k-2}(\text{b})$. That is, signals intended for STS compatible mobile-stations are included in both output signals $s_{\alpha-1}$, $s_{\alpha-2}$ and signals intended for non-STS compatible mobile-stations are included in only signal $s_{\alpha-1}$. Alternately, signal $s_{\alpha-1}$ comprises of signals S_{k-1} and S_{k-2}(b) and signal $s_{\alpha-2}$ comprises of signals S_{k-2}(a).

Signal $s_{\alpha-1}$ is split by splitter 34 into signals $s_{\alpha-1}$(a), $s_{\alpha-1}$(b) and processed along paths A and B, respectively, by multipliers 36, 38, 40, adder 42 and amplifiers 44, 46 in accordance with bias PSTD techniques. Basically, biased PSTD involves transmitting a signal and a frequency swept version of the same signal over diversity antennas at different power levels. Advantageously, biased PSTD is backwards compatible from the perspective of mobile-stations and does not degrade performance as much as PSTD in additive white gaussan noise (AWGN) conditions.

In one embodiment, signal $s_{\alpha-1}$ is unevenly power split by splitter 34 such that the power level of signal $s_{\alpha-1}$(a) is higher than the power level of signal $s_{\alpha-1}$(b). For example, signal $s_{\alpha-1}$ is power split such that signal $s_{\alpha-1}$(a) gets 5/8 of signal $s_{\alpha-1}$'s power and signal $s_{\alpha-1}$(b) gets 3/8 of signal $s_{\alpha-1}$'s power, i.e., $s_{\alpha-1}(\text{a})=\sqrt{5/8}\,(s_{\alpha-1})$ and $s_{\alpha-1}(\text{b})=\sqrt{3/8}\,(s_{\alpha-1})$. In another example, signal $s_{\alpha-1}$ is power split such that signal $s_{\alpha-1}$(a) gets 2/3 of signal $s_{\alpha-1}$'s power and signal $s_{\alpha-1}$(b) gets 1/3 of signal $s_{\alpha-1}$'s power. In another embodiment, signal $s_{\alpha-1}$ is evenly power split by splitter 34. Note that signal $s_{\alpha-1}$(a) is identical to signal $s_{\alpha-1}$(b) in terms of data. Signal $s_{\alpha-1}$(a) and carrier signal $e^{-j2\pi f_c t}$ are provided as inputs into multiplier 36 to produce signal S_{36}, where $S_{36}=s_{\alpha-1}(\text{a})e^{-j2\pi f_c t}$, $e^{-j2\pi f_c t}=\cos(2\pi f_c t)+j\sin(2\pi f_c t)$, f_c represents a carrier frequency and t represents time.

Signal $s_{\alpha-1}$(b) and phase sweep frequency signal $e^{-j\Theta_s(t)}$ are provided as inputs into multiplier 38 where signal $s_{\alpha-1}$(b) is frequency phase swept with signal $e^{-j\Theta_s(t)}$ to produce signal $S_{38}=s_{\alpha-1}(\text{b})e^{-j\Theta_s(t)}$, wherein $\Theta_s=2\pi f_s t$, $e^{-j\Theta_s(t)}=\cos(2\pi f_s t)+j\sin(2\pi f_s t)$ and f_s represents a phase sweep frequency.

Signal S_{38} is added to signal $s_{\alpha-2}$ by adder 42 to produce signal $S_{42}=s_{\alpha-1}(\text{b})e^{-j\Theta_s(t)}+s_{\alpha-2}$. Signal S_{42} and carrier signal $e^{-j2\pi f_c t}$ are provided as inputs into multiplier 40 to produce signal S_{40}, where $S_{40}=(s_{\alpha-1}(\text{b})e^{-j\Theta_s(t)}+s_{\alpha-2})e^{-j2\pi f_c t}$.

Signals S_{36}, S_{40} are amplified by amplifiers 44, 46 to produce signals S_{44} and S_{46} for transmission over antennas 48, 50, respectively, where signal $S_{44}=A_{44}\, s_{\alpha-1}(a)e^{-j2\pi f_c t}$, $S_{46}=A_{46}\,(s_{\alpha-1}(\mathrm{b})e^{-j\Theta_s(t)}+s_{\alpha-2})e^{-j2\pi f_c t}$, A_{44} represents the amount of gain associated with amplifier 44 and A_{46} represents the amount of gain associated with amplifier 46.

In one embodiment, the amounts of gain A_{44}, A_{46} are equal. In this embodiment, signal $s_{\alpha-1}$ is split by splitter 34 such that the power level of signal $s_{\alpha-1}(a)$ is higher than the power level of signal $s_{\alpha-1}(b)$ so that differences in power level between signals S_{44} and S_{46} are not as large compared to an even power split of signal $s_{\alpha-1}$.

In another embodiment, the amounts of gain A_{44}, A_{46} are different and related to how splitter 34 power splits signal $s_{\alpha-1}$. Specifically, the amount of gain A_{44}, A_{46} applied to signals S_{36}, S_{40} should be an amount that would cause the power levels of signals S_{44} and S_{46} to be approximately equal. For purposes of this application, power levels are "approximately equal" when the power levels are within 10% of each other. For example, suppose the power levels of both signals $s_{\alpha-1}$, $s_{\alpha-2}$ are x and splitter 34 splits signal $s_{\alpha-1}$ such that the power levels of signals $s_{\alpha-1}(a)$, $s_{\alpha-1}(b)$ are $7/8x$ and $1/8x$, respectively. After signal signals $s_{\alpha-2}$ is added to signal S_{38} by adder 42, the power level of the resultant signal S_{42} is $9/8x$. In this example, the amount of gains A_{44}, A_{46} might be 8/7 and 8/9, respectively.

In the case where signal $s_{\alpha-1}$ and/or signals S_{36}, S_{40} are not biased or unevenly split or amplified, STS performance will degrade because signal S_{44} will be transmitted at approximately 1/3 of the power at which signal S_{46} will be transmitted. Advantageously, biasing or unevenly splitting signal $s_{\alpha-1}$ and/or biasing or unevenly amplifying signals S_{36}, S_{40} mitigates this degradation to STS performance relative to the case where neither signal $s_{\alpha-1}$ nor signals S_{36}, S_{40} are biased or unevenly split or amplified.

FIG. 5 depicts a base station 70 employing CDMA, biased PSTD, STS/OTD and split shift PSTD in accordance an embodiment of the present invention. In this embodiment, , a form of PSTD referred to herein as split shift PSTD in also utilized. Spilt shift PSTD involves shifting both signals split from a single signal using phase sweep frequency signals that sweeps both signals in opposite direction. As shown in FIG. 5, signals $s_{\alpha-1}(a)$, is phase swept by multiplier 39 using phase sweep frequency signals $e^{j\Theta_s(t)}$. Although this embodiment depicts phase sweep frequency signal $e^{j\Theta_s(t)}$ equal and opposite to phase sweep frequency signals $e^{-j\Theta_s(t)}$, it should be understood that the phase sweep frequency signal used to phase sweep signals $s_{\alpha-1}(a)$ need not be equal in magnitude. In another embodiment, signal $s_{\alpha-1}(a)$ is phase

swept using a phase sweep frequency signal that results in phase swept signal $s_{\alpha-1}(a)$ with a desired or other phase difference to phase swept signal $s_{\alpha-1}(b)$. Note that that the phase sweep frequency signal used to phase sweep signals $s_{\alpha-1}(a)$, $s_{\alpha-1}(b)$ may be phase shifting at an identical or different rate from each other, may be phase shifting at fixed and/or varying rates, or may be phase shifting in the same or opposite direction.

Although the present invention has been described in considerable detail with reference to certain embodiments, other versions are possible. For example, phase sweeping may be performed along path A instead of path B, i.e., signal $s_{\alpha-1}(a)$ is phase swept with signal $e^{-j\Theta_s(t)}$. FIG. 4 depicts a base station 60 in which phase sweeping is performed along path A instead of path B. Therefore, the spirit and scope of the present invention should not be limited to the description of the embodiments contained herein.